# iSCIENCE

THE SCIENCE MAGAZINE OF IMPERIAL COLLEGE

## SUPER SCIENCE

I, SCIENCE

THE SCIENCE MAGAZINE OF IMPERIAL COLLEGE

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# I, SCIENCE

Nature is a constant source of wonder and more of the natural world is discovered all the time using the methods of science. Although in a Super Science issue you may expect a lot of the subject matter to be out of this world, it's from understanding natural processes, such as evolution, that let us recognise how extraordinary life can be. Lauren Hoskin times the rate of speciation in her article Super Speedy Evolution and notes the incredible rapidity at which, for example, the freshwater guppy can evolve.

Alisa Crisp also tours some of the most unlikely natural adaptations in her piece on Super Survivors and asks whether these extremophiles could be responsible for transporting life around the universe. But the Super Science issue doesn't just explore the peculiarities of nature. Rosamund Pearce writes on the information superhighway of today's Internet while Daisy McInnerney runs through current and future applications for nanotechnology in her article on Mega Materials. The progress of nanoscience has meant we can manipulate the structure of some materials atom by atom. Nanomaterials are already gently seeping onto store shelves and into our lifestyles and this is only likely to continue over the coming years.

No issue on Super Science would be complete without a run through the superpowers of our comic book heroes and Christopher Yates asks what he needs to do to join their ranks. He identifies three types of superheroes: those born with the power, those who acquire it through experimentation and those who rely on technology for their ability. With advances like adhesion pads and invisibility cloaks, Chris asks how close we are to emulating these giants of our science fiction culture.

As ever, we've included our pick of news since the last issue from Imperial College and beyond, along with book and event reviews. This issue also sees the return of the Science Behind The Photo centre page spread. We hope you enjoy our plunge into the startling, mysterious, fantastic and sometimes downright scary arena of Super Science. ■

TOM

**Here at I, Science we're always on the lookout for potential new contributors for both the magazine and the website.**

**If you are interested and would like to get involved as a writer, editor or illustrator please don't hesitate to get in contact. You can email us at i.science@imperial.ac.uk, tweet us @i_science_mag or contact us directly through**

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# NEWS FROM
## IMPERIAL COLLEGE

Image: Linda Bartlett

## OPENNESS ON ANIMAL RESEARCH

The Concordat on Openness in Animal Research has been signed by 72 organisations including commercial companies, universities and charities. Imperial College has also signed.

Commitments of the concordat include clarity on the purpose of animal research, more communication about research undertaken, and a promise to be proactive on informing the public about using animals in research.

Professor Maggie Dallman, Chair of the newly created Animal Welfare and Ethical Review Body, said: "My hope is that the Concordat will help organisations working in this area give their staff the confidence and support that they need."

It comes in the wake of the action plan recently published by Imperial College with the aim of improving the welfare of animals used in research at the college. That plan followed allegations of "shortcomings and wrongdoing by staff and researchers" made by the British Union for the Abolition of Vivisection (BUAV).

An independent committee, led by Professor Steve Brown, published a report on Imperial College's use of animals in research in December 2013 and, although the committee commended the college on the high standards of animal husbandry and care in some areas, it was slammed with Brown stating that "there needs to be significant improvement."

Brown's report highlighted an "ad hoc" approach to competency assessment, supervision and training of staff in animal research laboratories. The action plan responded by including the recruitment of a Director for Bioservices to provide overall strategic leadership and direction, strengthening the application of replacement, reduction and refinement of animals in research (known as the 3Rs) and implementing more effective internal and external communication.

The action plan, along with the Concordat, will improve the accountability and transparency of the College's approach to research on animals. ■

BEN STOCKTON

## C-SECTIONS LINKED TO OBESITY

Imperial Researchers determine link between babies born via C-section and obesity later in life.

The new analysis carried out by researchers at Imperial College shows that children born by caesarean section are more likely to be obese when they reach adulthood.

The finding was based on the combined data of 15 studies from across ten countries, bringing together the history of 38,000 participants. The study found that for those born by caesarean section, there is a 26% increase in the chances that the child will be overweight or obese as an adult.

However, as is the issue with all combined data analyses, it cannot be certain whether the delivery method is, in fact, causal of the higher body weight, as it may also have been influenced by other factors that were not recorded.

Professor Neena Modi from the Department of Medicine at Imperial College London, an author of the paper, said of the uncertainty: "We now need to determine whether this is the result of the C-section, or if other reasons explain the association." Despite this, previous research has associated C-sections with other adverse long-term health effects such as asthma and type 1 diabetes.

The benefits of a vaginal birth over a C-section are numerous, and some may lie in the exposure of the newborn to the healthy bacteria that reside inside the birth canal. Not only that, but there also may be influences on gene expression that stem from the physical compression of the baby as it is born.

With around one in four births now requiring a C-Section, a figure that is steadily on the rise, this research could highlight new, long-term effects of the growing trend. The researchers pointed out that although there are good reasons why many woman may have a C-section, this could be one more factor that needs to be considered. ■

PHILIPPA SKETT

# DRUGS LIVE RESEARCH PUBLISHED

Research led by David Nutt, Professor of Neuropyschopharmacology at Imperial College, and Professor Val Curran from UCL indicates that ecstasy, or MDMA, could be used therapeutically.

Part of the research was documented by Channel 4's *Drugs Live* show in 2012 where volunteers took 83mg of MDMA or a placebo in a double-blind study live on air. The findings have now been published in *Biological Psychiatry*.

By using functional magnetic resonance imaging (fMRI) it was possible to image brain activity whilst healthy volunteers were under the influence of MDMA, a popular recreational drug. The effects on the activity of the brain were the opposite of those seen in patients with post-traumatic stress disorder (PTSD), an anxiety disorder that can develop following severe trauma.

Volunteers were asked to recall favourite and worst memories whilst under the influence of MDMA. Dr Robin Carhart-Harris, who performed the research, said: "In healthy volunteers, MDMA seems to lessen the impact of painful memories," suggesting that "it could help patients with PTSD revisit their traumatic experiences in psychotherapy without being overwhelmed by negative emotions."

The study showed that MDMA reduces limbic activity and decreases communication between the medial temporal lobe and medial prefrontal cortex, which are involved in emotional responses and control respectively.

Although the research is promising, Nutt is clear he doesn't want to draw too many conclusions until studies are carried out in anxiety patients.

Our knowledge of how MDMA affects the brain is severely limited as researchers are restricted by UK drug laws. Nutt has been critical of the government stating that "it's the dark ages beginning to descend on this field". He was awarded the 2013 John Maddox Prize in recognition of his courage in "promoting science and evidence on a matter of public interest, despite facing difficulty and hostility in doing so." ■

BEN STOCKTON

# HEALTH CENTRE'S NEW STRATEGY

The Academic Health Science Centre (AHSC) set out its vision for the future of healthcare at a recent Imperial College event and further cemented its place as a cornerstone of health research delivery.

Imperial established the first AHSC in the UK in 2007 with the NHS trusts from Hammersmith and St Mary's Hospitals. Since then, the format has been rolled out at Cambridge University, Kings College London and Manchester University among others.

Presentations at the event outlined the strategy for the period 2014-19. Director of Imperial College AHSC Professor David Taube called the centre "an integrated structure that brings together all aspects of the College and Trust."

Taube feels the forward thinking strategy will "allow us to use new technologies to put first-class healthcare not just by patients' bedsides but into people's bedrooms."

Similar centres have opened in countries around the world including the Netherlands, the USA, Ireland and Sweden. Not only do they provide a means to deliver cutting edge medical discoveries to patients but they also form a platform for sharing information.

Chairman of Imperial College AHSC Sir Gordon Duff feels that Imperial's new strategy will feed into this international network: "We're creating an AHSC that will drive – not follow – the healthcare agenda in the UK and Europe," he said.

Alongside the speeches, there was an exhibition of some of the latest technologies coming out of the Centres for Translational Medicine (CTM), which deliver the research to frontline healthcare. One CTM recreated heart surgery in a pop-up operating theatre, while the CTM for Brain Sciences and Diseases demonstrated their 'EEG Pong', a game that translates brain wave activity of the user into actions in a table tennis video game.

The Imperial College AHSC continues to prove itself as an effective way to speed up the time it takes for the NHS to access the latest and best quality treatments. ■

TOM BRAGG

Image: Tom Varco

# WORLD NEWS

## PICK OF THE BEST

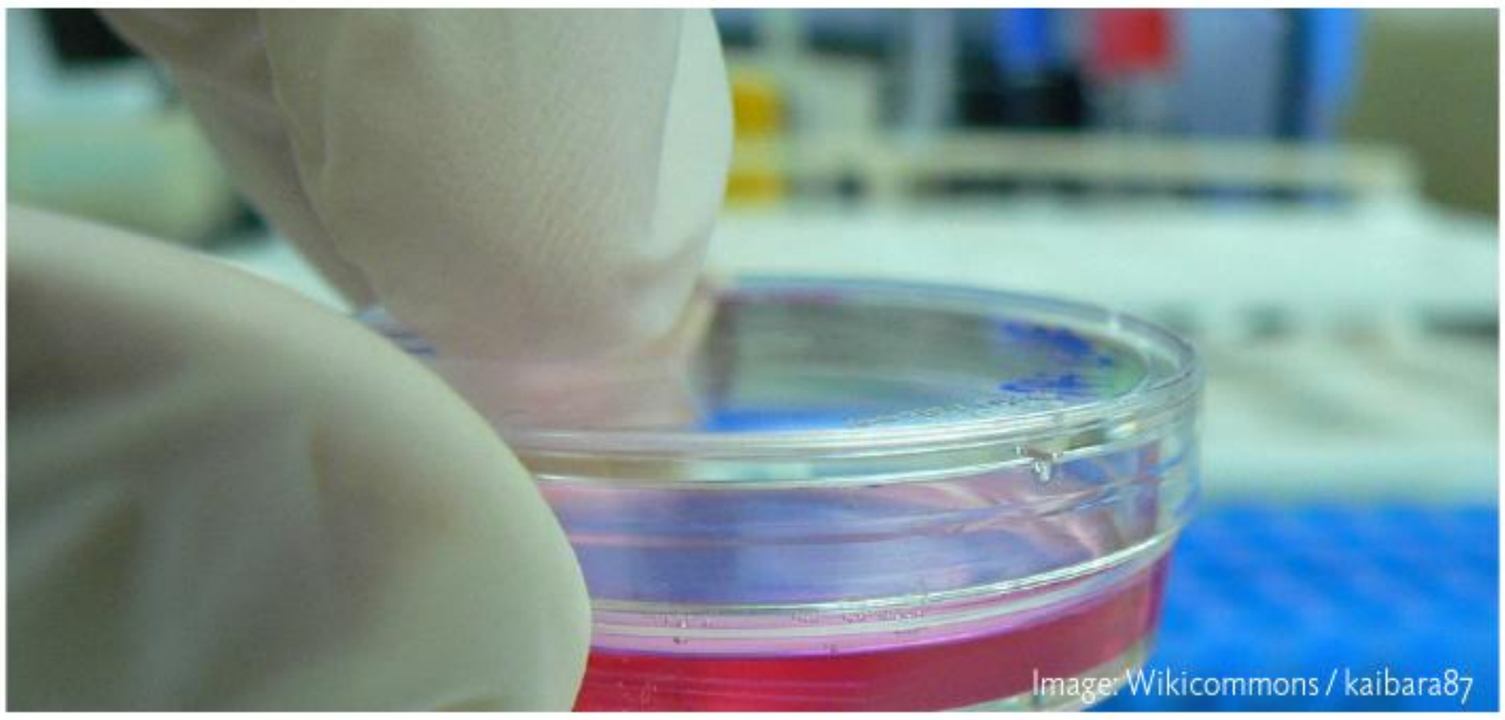


Image: Wikicommons / kaibara87

## SUPER BUGS

The discoverer of penicillin, Alexander Fleming, foretold the problems of antibiotic resistance during his Nobel Prize speech in 1945. Less than a century later, drug-resistant bugs can already be found in every region of the world.

According to a recent report by the World Health Organisation (WHO), this situation will bring disastrous global health consequences unless significant action is taken urgently.

In recent years, a growing number of pathogens have stopped responding to the standard antimicrobials that were used to combat them. The WHO report found very high rates of resistance in the bacteria that commonly cause infections in hospitals and in the community.

In short, some of the most effective weapons we had against common diseases have been rendered worthless. This means infections are harder to control, the risk of the spread of infection to others increases, illnesses and hospital stays are prolonged, and doctors are increasingly forced to turn to last resort treatments. Resistance is caused by the rapid evolution of bacteria but much of the responsibility for resistance lies in the abuse and misuse of antimicrobials. Doctors overprescribing antimicrobials, patients failing to take their full treatment, and farmers feeding them to animals, all mean resistance is happening much faster than expected.

Last year, the UK introduced a five-year plan to improve the use of antibiotics, shore up surveillance of resistant microbes and develop tests for infections. The WHO encourages these measures and emphasises the crucial need to strengthen collaboration on global coordinated surveillance.

Jeremy Farrar, head of the Wellcome Trust, and Mark Woolhouse, Professor of infectious disease epidemiology at the University of Edinburgh, have urged world leaders to create an international body, based on the structure of the Intergovernmental Panel on Climate Change, to systematise evidence and mobilise government sectors and society as a whole. This is a global problem that requires a global response; the achievements of modern medicine are at stake. ■

NICOLE SKINNER

## FUSION TIPPING POINT

A team based at Lawrence Livermore National Laboratories have reached a new milestone in energy output. Recent research, published by *Nature* journal, shows that a fusion experiment has produced more energy than the amount put into the fuel - an achievement that has been an ambition of plasma physicists since the 1950's.

In the $3.5 billion laser-based system, each fusion attempt, or 'shot', begins with splitting one weak laser pulse into 192 beams then amplifying each one through special mirrors and crystal optics, before focusing them on the target. The final power of each laser is 4 million joules – the most powerful in the world – and is reached in about 1.5 microseconds.

The target is a poppy seed-sized pellet composed of the hydrogen isotopes tritium and deuterium. The pellet is encased in a 9x5 millimetre gold cylinder called a hohlraum. The beams arrive within picoseconds of one another, entering the top and bottom of the hohlraum. The intense energy of the beams heat the inside, inducing the emission of x-rays from the gold walls and this radiation compresses and heats the plastic shell around the fuel, creating the conditions needed to kick-start the fusion process.

If, or when, the NIF achieves the self-sustaining fuel burn of true 'ignition', the announcement will be heralded on front-page headlines around the world; yet this news confirms that the ambitious project is on track. "This is not a multi-decade problem now, if you get to ignition. That's what's so exciting", said Dunne.

That's what drives me and drives the teams, and a lot of the students who come through can see it happening now," said Dunne. "The pathway to a power plant is not something their children will do, or grandchildren will do, it's something that they can do in their research careers." ■

ALIYAH KOVNER

# HEAVY WEATHER

The chances of heavy winter rainfall on the south of England have increased by 25% since pre-industrial times according to research carried out by a team at the University of Oxford.

Catastrophic floods like those experienced earlier this year are now predicted to happen once every 80 years, rather than once every 100 years, which was the previous estimate.

It's been widely reported that one reason for last winter's extreme weather could be manmade global warming. Research presented at the AAAS meeting at Chicago suggested that with more of the Sun's radiation hitting Earth, comparatively more will hit hot areas within the tropics than will hit more northerly latitudes. That larger difference between the temperature at mid and more northerly latitudes could speed up jet streams that move in a north easterly direction across the Atlantic and Pacific oceans.

Speaking on the extreme weather at the Chicago meeting, Professor Jennifer Francis of Rutgers University in New Jersey said: "We can expect more of the same and we can expect it to happen more frequently."

The immediate trigger for the UK storms was attributed to unseasonable storms in Indonesia that led to an acceleration of the jet stream across the Pacific. This pushed the warm, wet air further north than it normally goes leading to a 'polar vortex' and a harsh winter in the United States with temperatures as low as -26 °C in the Midwest.

It was thought this had a knock on effect for the Gulf Stream over the Atlantic that caused it to move faster and bring with it wave after wave of storms.


Image: Flickr / Ministry of Defence

The 2013/14 winter was the wettest since records began in 1766. If Professor Francis and her research team are correct, these periods of persistent rainfall are likely to stay.

TOM BRAGG

# OPEN ACCESS FLOURISHES FURTHER

Two of the largest funders of research, the National Institute of Health (NIH) and the Wellcome Trust, have begun to withhold grant payments for research that was not published under an open access license.

The Wellcome Trust withheld grant payments 63 times in the last year and the NIH has also discontinued grants since July 2013 on a number of occasions because the research wasn't published open access. As a result, the compliance rate to open access of the NIH has gone up from 75% to 82% and that of the Wellcome Trust has increased from 55% to 69%.

There are more places to publish open access research than ever before. In February 2014, The Royal Society announced the launch of a new journal called *Royal Society Open Science*. The new journal publishes across a broad range of disciplines, offers open peer review as an option, and also has article level metrics to encourage post publication comments.

The American Association for the Advancement of Science (AAAS) have followed suite and announced the launch of their first open access journal, *Science Advances*. It follows on the heels of open access journal *Scientific Reports*, which was started by their competitor Nature Publishing Group in 2011.

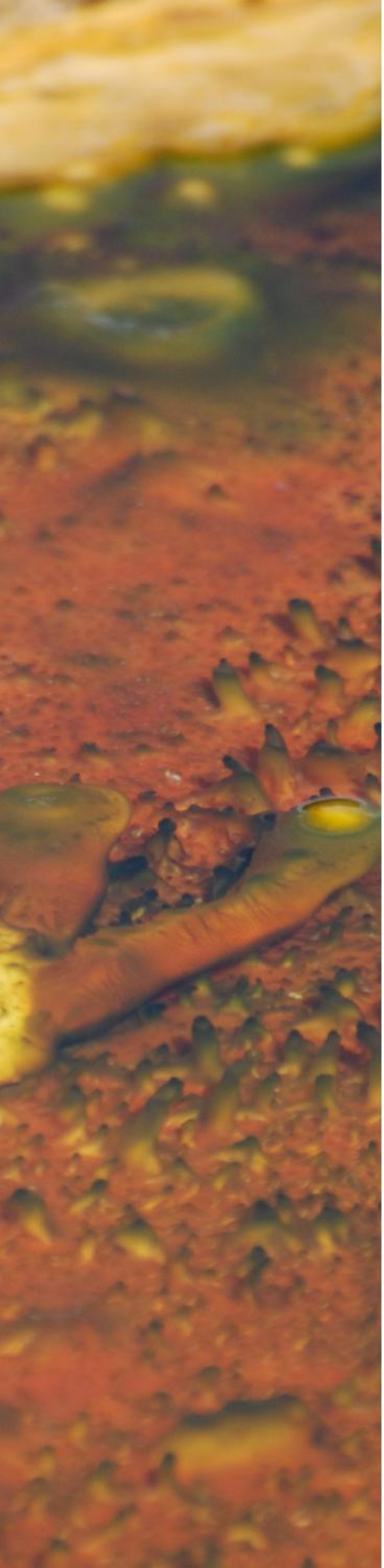
The Wellcome Trust have gone a step further and launched a new online platform called Mosaic under the most liberal open access license - CC-BY. The website actively encourages all of their content, with the exception of a few photos, to be republished on other platforms for commercial or non-commercial purposes. Their 'Killer Dust' piece has been republished on the *I, Science* website.

Finally, the Science Museum Group Journal also started under the CC-BY license and puts out articles about science history and communication, material culture and museum display and presentation.

Currently, the NIH and the Wellcome Trust are the only two funders worldwide that suppress grant payments due to non-compliance with open access policies, but with the continued rise of the open access model it is believed that other funders may follow in their footsteps in years to come.

DALMEET SINGH CHAWLA

Image: Flickr / OnceAndFutureLaura



# SUPER SURVIVORS

*Extremophiles thrive in the most uncomfortable places.* ***Alisa Crisp*** *visits their habitats, on Earth and beyond.*

From well below freezing to boiling water, from the crushing pressure in deep ocean trenches to the thin air above Mount Everest, many different types of life have adapted to live in extreme conditions – these, are the extremophiles. The benefits are great for those that can survive; there aren't many competitors or predators where nothing else lives.

The solutions that different organisms have developed over millions of years are fascinating. Insects pump their bodies full of antifreeze to survive down to -150°C, witness the red flat bark beetle (Cucujusclavipes) that lives in northern Alaska. Sahara Desert ants (Cataglyphisbicolor) can survive a mid-day heat that reaches 60°C, albeit for only three to five minutes per day; they have silver bodies to reflect the heat, long thin legs and an accurate navigation system to get home quickly.

Deep in the ocean, Pompeii worms survive both high pressure and high temperature, living alongside volcanic vents at around 80°C. The worms have a symbiotic relationship with thermophilic bacteria, which might be how they survive.

However, the tardigrade, or water bear, wins the competition for a multicellular organism that can survive almost anything. It is a polyextremophile so can survive a variety of extreme environments, from very close to absolute zero (less than -270°C) up to 150°C. They have been known to survive in a dehydrated, hibernation-like state for over a hundred years without food or water. Neither high nor low pressures are a problem for these creatures, which have survived in space, and at pressures six times higher than the bottom of the ocean, even surviving radiation blasts.

Why they have evolved to be this resistant is still a mystery. Their normal habitat is moss and lichen – not the most challenging of environments. Although why is not the interesting question here; scientists are currently looking at how they survive these conditions and what we could learn from their physiology.

Bacteria and microorganisms are another area for research, psychophilic (cold-loving) and thermophilic (heat-loving) microorganisms are being studied to find new enzymes and reactions that are optimised for different temperatures and that could be used in industrial reactions. For example, PCR (polymerase chain reaction) for DNA amplification is not possible without the thermostable enzymes that survive cycles at 90°C, originally found in the bacterium *Thermusaquaticus*.

If life can survive more extreme conditions, there are more places to look, including in our solar system. Endoliths are organisms (including bacteria, lichen, algae and amoeba) that live in rock or minerals but one species has been found that lives for millions of years by slowing its reproduction cycle – each generation has a reproduction cycle every 10,000 years. Astrobiologists hope that these organisms could potentially live on other planets, for example, endolithic conditions have been found on Mars, and so studying them is important in the search for extra-terrestrial life. Extremophiles have implications for panspermia, the theory that life does exist throughout the universe and is distributed by comets, meteoroids and planetoids. For this to occur, life would have to survive conditions in space, as well as ejection from one planet and entry to another – extremophiles are the prime candidates for this.

From the deepest oceans to deeper space, extremophiles are telling us ever more about the world we live in and, potentially, those of other life-forms. ■

# DEEP SEA MYSTERY

*The super depths of the ocean are unexplored terrain.* ***Laura Childs*** *charts the small amount that's known.*

This summer, Academy Award-winning director James Cameron will release his latest film about deep sea exploration. But this time, it's not a fictional account, and the main star is Cameron himself.

In March 2012, Cameron descended nearly seven miles beneath the surface of the western Pacific Ocean for the deepest solo dive in history. At the southern end of the Mariana Trench, which lies between Japan and Papua New Guinea, the Challenger Deep is the deepest known point on Earth, and has only been visited once before: in 1960, by oceanographer Jacques Piccard and navy lieutenant Don Walsh.

While Cameron's primary motivation was pure curiosity, the mission was also designed to be a scientific exploration of one of the least visited parts of the planet. The purpose-built submersible, Deepsea Challenger, collected data, samples and 3D imagery during the expedition and analysis of these results is still ongoing. Deepsea Challenger has since been transferred to the Woods Hole Oceanographic Institute in Massachusetts to help future deep sea exploration.

It's estimated that only around 5% of the world's oceans have been explored by humans to date, mainly due to deep sea exploration being expensive, difficult and dangerous. But as the number of manned submersibles increases, and with developments in robotics providing autonomous underwater vehicles, deep sea exploration is undoubtedly making progress.

Conditions at the bottom of the ocean are extreme. Natural light can't penetrate the sea much further than 200 metres below the surface, resulting in total darkness. Barometric pressure increases by one atmosphere for every 10 metres you descend, causing crushing pressures. Deep ocean water typically fluctuates between 0°C and 3°C in temperature, yet hydrothermal vents on the seabed expel water at temperatures as high as 400°C.


Image: Oisin Mulvihill

> IT'S ESTIMATED THAT ONLY AROUND 5% OF THE WORLD'S OCEANS HAVE BEEN EXPLORED BY HUMANS TO DATE

Given such harsh conditions, scientists had previously assumed that life would be scarce, but once the tools were developed to explore this alien environment, the deep ocean turned out to contain an incredible biodiversity. Some scientists have estimated that as many as 10 million species live down there, making the levels of biodiversity in the ocean comparable to that of the world's rainforests.

In order to survive in these extreme environments, deep sea creatures have had to adapt in unusual and unique ways. Photosynthesis is impossible so plants, the primary producers of nearly all of Earth's ecosystems, can't survive. Where do the organisms get their energy from?

Many depend on organic matter sinking from the more hospitable regions above, in what's known as 'marine snow'. But some creatures living around mineral-rich hydrothermal vents on the sea floor, use chemosynthesis — the process of using energy released by inorganic chemical reactions to produce food.

Giant tube worms rely on chemosynthetic bacteria living within them that oxidise hydrogen sulphide expelled from the vents using dissolved oxygen in the seawater. This provides the energy they need to produce organic molecules. Revealing chemosynthesis is considered to be one of the great scientific discoveries of the last century, and the process has been speculated to be behind the origins of life on Earth.

Deep sea chemistry is also responsible for bioluminescence, which is used by many deep sea organisms to produce light through chemical reactions. The light is used to see, lure prey, attract mates, or distract predators, in an otherwise pitch-black environment.

Female deep sea anglerfish use bioluminescent 'baits' on the end of their protruding dorsal spines to lure their prey. The 'baits' are bulbous growths full of bioluminescent bacteria, which enter the bait from the surrounding seawater through small pores, and stay there because they get access to nutrients provided by the host anglerfish in exchange for their bioluminescent properties.

Due to the rarity of encounters in the deep ocean, some anglerfish have also developed an unusual method of reproduction. When a male ceratioid anglerfish finds a female, he grips on with pincher-like tentacles and the two fuse together, eventually uniting their circulatory systems. The male's body then atrophies and he becomes permanently dependent on the female for nutrients, in return providing sperm whenever she requires it. In some species, a single female host can be coupled to as many as eight males.

Given the range and novelty of species found in the deep sea, it's not surprising that the search for valuable new commodities, which are in short supply on land, is now moving underwater.

> DEEP SEA BACTERIA COULD HAVE VALUABLE PROPERTIES INCLUDING POSSIBLE NEW ANTIBIOTIC AGENTS

As antibiotic resistance increases, researchers are going to further extremes than ever before in their efforts to discover new ones. The PharmaSea project, launched last year, is a collaboration between European scientists hoping to find new bioactive compounds from marine organisms.

Due to the remote nature of these hostile environments, life in each deep sea trench has evolved in very different ways, encouraging hopes of discovering a wide variety of novel microorganisms. By collecting mud and sediment samples from deep sea trenches, and culturing them back in the lab, researchers believe that the resulting deep sea bacteria could have valuable properties including possible new antibiotic agents.

And it's not just drugs on offer either. Vast reserves of minerals, including rare-earth metals, are known to exist in the seabed. These are key components of our much-loved smart phones and burgeoning hybrid car industry and are currently in short supply. The deep sea is therefore predicted to be the next big target for mining, and 19 leases have already been issued for prospecting in international waters, covering a combined area the size of Mexico.

But because we know so little about the deep ocean, it's hard to know what the effects of such invasive exploration could be. In February, scientists warned that we need to stop and think before moving ahead with this relatively new type of resource extraction. Given the harmful effects that have arisen from the large-scale destruction of the rainforests, there's a pressing need for research to be carried out, and possible regulation put in place, before the world's oceans are exploited.

As technological advancements make exploration of the deep sea easier, one of the last great unexplored regions on Earth is about to become a little more familiar. Let's treat it with the respect it deserves. ■

# EVOLUTION'S TOP 6 SUPER ADAPTATIONS

*From the ingenious to the ridiculous, the direction evolution has taken in creating creatures great and small never fails to amaze. Here is a selection from* ***Hannah Wilson*** *of six startling super adaptations, from high flying circulatory systems to self-applied sun cream.*

## HIGH FLYERS

Bar-headed geese breathe more deeply and efficiently under low oxygen conditions, which helps them fly at high altitude. Their hemoglobin has greater affinity for oxygen, which has been attributed to a single amino acid mutation that causes a conformational shift in the hemoglobin molecule. Also, the left ventricle of their hearts - responsible for pumping oxygenated blood to the body via systemic circulation - has significantly more capillaries in bar-headed geese than in lowland birds, maintaining oxygenation of cardiac muscle cells and therefore cardiac output. This enables the geese to sustain the huge metabolic demands of high altitude flight.

## BANG, BANG YOU'RE DEAD

Pistol shrimps have one disproportionately large claw with two interlocking parts in the place of pincers. When it pulls the limb structure back and releases, the built up pressure creates a wave of bubbles that contain energy with as much heat as the surface of the sun. These 'bullets' from the John Waynes of the sea create shock waves that knock out potential predators. They can also shoot-from-the-claw to stun prey for the shrimp to eat.

## NO LAUGHING MATTER

The poor female spotted hyena has a vagina that is fused shut, resulting in a pseudo-scrotum. Intercourse, urination, and birth are all performed through the female's massively enlarged clitoris. The strange organ matches the male's penis in both size and hardness. Scientists are still struggling to understand why the female hyena has evolved this trait, especially given that one out of every ten births results in the death of the mother. The evolutionary benefit of this trait remains a complete mystery.

## TOUCH SENSITIVE

The pantropical weed Mimosa pudica, which grows mostly in shady areas under trees or shrubs, has leaves that fold up when touched. The mechanism for the adaptation involves specific regions on the stem that are stimulated to release potassium ions. These force water to diffuse out of the cell leading to a loss of cell pressure and cell collapse. The differential turgidity between different regions of cells results in the closing of the leaflets and collapse of the leaf petiole. The mechanism is thought to act as a defense against herbivores that may otherwise feed on the plant.

## ICY GAMBLE

Several species of frogs and turtles have evolved to freeze solid during the winter and then thaw back to life in the spring. This outstanding way of surviving cold spells is explained by the fact that the urea and glucose in their blood reduces the osmotic shrinkage of cells caused by the cold conditions, which would otherwise lead to their death. There is, however, a limit to their resistance: although they appear rock solid when frozen, the survival of these animals is compromised if more than 65% of the water in their bodies freezes.

## CRÈME DU SOLEIL

Surviving in the sub-Saharan African sun is a challenge not many could achieve, but hippos have developed their own natural sunscreen. The substance oozes out of their pores in a shocking, bright red color. This strange secretion is aptly named "blood sweat," although it contains neither of those two bodily fluids. Instead, it is made up of a number of highly acidic compounds that absorb ultraviolet light, preventing sunburn and also inhibiting the growth of bacteria.

# SUPERTERRESTRIAL CIVILISATION

*What parts of our solar system are realistically accessible?* ***Emma Wills*** *rockets through our space travelling potential.*

"Sooner or later, we must expand life beyond our little blue mud ball—or go extinct."

*Elon Musk, founder of private spaceflight company SpaceX*

Space travel and exploration has been described as the natural future for the human race by many throughout history, but when the furthest we have travelled is to our own moon, and with far less than one per cent of NASA's highly trained and dedicated applicants selected for eventual spaceflight, are we a species really capable of leaving Mother Earth behind?

Although over 119 human years have been spent in space, that question is still being answered. The longest space mission to date was carried out by Valeri Polyakov, who spent 437 days aboard the space station Mir in 1995. He is a doctor specialising in space medicine and took part in the mission to demonstrate that humans can survive long enough periods in space to travel to Mars.

Whilst in space, his cognitive abilities and reactions were tested, and "an impressive stability of mood and performance were observed." The only drops in his performance came in the days before and after take-off and for a few weeks after returning to Earth, which were put down to the extra stress on the brain from acclimatising to and from weightlessness.

Polyakov was not an ordinary man. He had already spent 240 days in space before this mission, and completed 19 years of training before that. The fact he climbed out of the Soyuz capsule unaided and walked the short distance to a nearby chair after landing was widely hailed as an amazing result, but that this was seen as something so remarkable shows the truth of the rigours even the best prepared human body undergoes during space travel.

In microgravity astronauts face major muscle and bone loss unless osteoporosis drugs and a large amount of exercise are taken. Blood pressure equalises throughout the body and so increases in the head, telling the body to produce less blood and causing the heart to atrophy. Recently, eyesight problems have been noticed in astronauts, leaving them farsighted, a major problem for people dealing with fine tools and instruments. Sleep deprivation is another concern for astronauts, causing many to have periods where they struggle to complete basic tasks and nod off mid-conversation.

> "INCREASINGLY, THE BOLDEST FUTURE EXPLORATORY MISSIONS ARE BEING SUGGESTED BY PRIVATE COMPANY."

It is being increasingly suggested that automated systems should be introduced to help monitor and aid these human errors. It seems that sometimes, far short of being the necessary, innovative and reliable parts of a space-mission, human participation causes many of the problems. So, if human space travel is limited, what about unmanned craft? How much of our galactic neighbourhood have our spacecraft succeeded in exploring?

The furthest object we have sent into space is Voyager One, which was widely hailed as entering interstellar space at the end of August last year after more than 35 years of travelling. This may seem relatively speedy, but strictly speaking the spacecraft is only thought to have left the heliosphere, which is the bubble of electrically charged particles that surrounds the sun, and is actually nowhere near leaving our solar system. Far outside of the heliosphere - another 200 to 300 years of Voyager's travelling time away - stretches the Oort Cloud, a vast expanse of icy comets that may take Voyager over 30,000 years to emerge from the other side of. When it comes to exploring, we really are stuck within the confines of our solar system.

Even around the sun, our exploration is mostly limited to the closest planets. Mars is the most explored planet with 41 missions to study it so far attempted, and two currently en route. Over half of them have been failures. The successful ones have made their own records - NASA's Opportunity rover has driven over 22 miles on

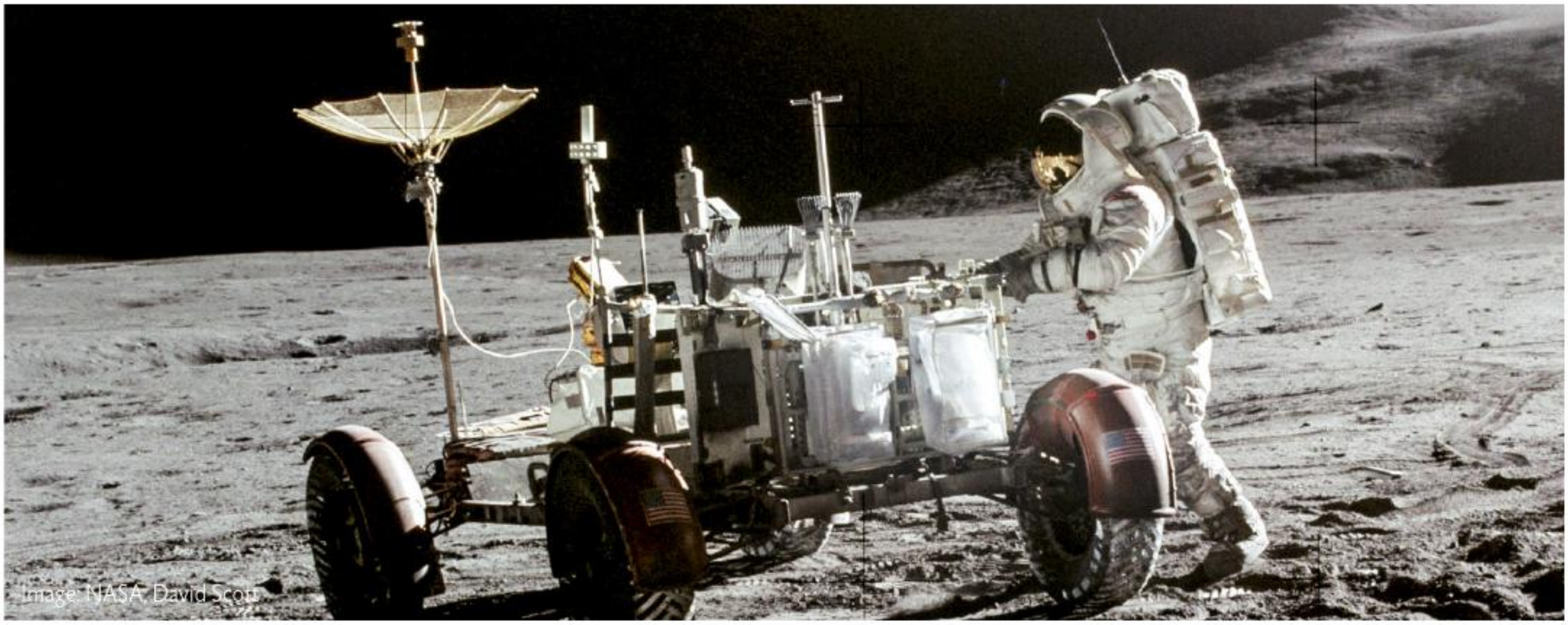


Image: NASA, David Scott

Mars, the furthest any vehicle has driven on another planet. Mars is actually our second closest planet, but has always been fashionable to explore because of the hints of water having once flowed on its surface taunting us with the prospect of potential life. Venus is actually our closest planetary neighbour and is known to have a thick and inhospitable atmosphere that maintains incredibly high temperatures. The number of visits to planets further out is far lower. A flyby from Voyager Two is the only human contact that Neptune and Uranus have ever received, and Jupiter and Saturn have each been on the end of just four space missions.

Sometimes though, objects from the extremities of our solar system come to us. This November, Rosetta's lander Philae will make the first ever controlled landing on a comet. Comets are chunks of dust and gas that littered the early solar system but were left out of planetary formation. They are the closest link we have to the original material of the nebula from which our sun and planets formed, and are thought to carry the complex organic molecules that may have kick-started life on Earth.

Rosetta is a European Space Agency project that left Earth in 2004 but, increasingly, the boldest future exploratory missions are being suggested by private companies. Mars One for example, promises to make history if its funding is reached and it puts a first wave of human colonists on Mars by 2025. Funds for the mission are being raised through private investment coordinated by for-profit company Interplanetary Media Group.

A whole host of other companies, including Planetary Resources Inc, plan to mine asteroids close to the Earth for a variety of resources from water to platinum. Commercial space projects like these, with business plans designed to attract investors, customers and press coverage are competing with traditional government-run space agencies like NASA that have to work within limited budgets.

It remains to be seen whether these more intrepid missions will get the funding they need. The main achievement of private company SpaceX, for example, has been to successfully reproduce relatively simple tasks such as getting safely in and out of the Earth's orbit and sending unmanned spacecraft to the International Space Station.

Perhaps extensive promotion of the next innovative and publically accessible space mission, like the reality TV show that Mars One is proposing to help select its final colonisation candidates, will enable the required funding to be raised. Or perhaps the true limit to our space adventures will come down to something far less prosaic than the top speed of our rockets or the limits of human endurance. ■

*America's Cup victory: Oracle Team USA drop off their hydrofoils as they cross the finish line ahead of Team New Zealand*

# SCIENCE BEHIND THE PHOTO

Last September British sailing legend, Sir Ben Ainslie, guided Oracle Team USA to America's Cup victory in one of the most astonishing sporting comebacks of all time. Hosted in San Francisco, this 34th America's Cup Series saw USA and New Zealand race head-to-head in state-of-the-art 72ft catamarans, battling to rack up a winning total of nine victories. Trailing the Kiwis 8-1, Oracle drafted in Ainslie as their tactician in a last-ditch effort to avoid defeat on home waters. In Ainslie's words, Oracle had "a mountain to climb".

Almost unrecognisable as sailing boats, the 'AC72' catamarans of this Cup Series pushed the limits of aerodynamic and hydrodynamic technology, reaching speeds of up to 55mph – nearly three times the wind speed that propelled them.


**Sailing faster than the wind**

The secret to this surprising feat lies in the AC72's unique sails. In place of traditional fabric sails, the AC72 sports a gigantic rigid panel, similar in size and shape to the wing of a 747 jumbo jet. Not only does this catch a huge amount of wind, but its asymmetric profile also pulls the boat forwards through the water. This works in the same way that an aeroplane wing generates lift: wind passing over the rear of the sail moves faster than wind passing over the front, generating a pressure difference that sucks the boat forwards.

The speed produced also lifts the 7-tonne boat out of the water, onto its carbon fibre hydrofoils – surfboard-sized projections extending downwards from the hulls. Gliding on its foils, the boat flies over oncoming waves rather than forcing its way through them, reducing drag and increasing the boat speed by 10-15%.

And the magic ingredient? Dinghy-sailing champion, Ainslie, calling the shots. Seven days after he joined the crew, Oracle lifted sailing's most prestigious prize. The final score: 9-8. ■

IMAGE & WORDS: ELLIE PINNEY

# SUPERHERO SCIENCE

***Christopher Yates** assesses how the heroes of comic books got their superpowers and asks whether he could ever join their ranks.*

Spider-Man swinging through the Manhattan skyline. Batman cruising round Gotham in his Batmobile. Tony Stark climbing into the Iron Man suit. Being a superhero looks very cool. Certainly, that's what David Lizewski, the alter ego of the hero Kick-Ass, thinks. Armed with just a wetsuit and some batons wrapped in electrical tape, Kick-Ass takes to the street to become a real-life superhero, receiving some horrific injuries in the process. Like other comics, Kick-Ass is fiction, but what if I wanted to become a superhero? Could science help me?

In comics, there tends to be three groups of superheroes. Some are born with their powers, such as the X-Men who have genetic mutations or Superman who came from another planet. Other superheroes receive their powers through experimentation, such as Captain America, or by accident, like Spider-Man. Finally, there are characters like Batman, who don't have any powers but become superheroes thanks to technology. My lack of super-powered mutations means I'll be looking to emulate the latter group.

After being bitten by a radioactive spider, Peter Parker developed spider-like powers, such as agility, strength and a 'spider-sense', alerting him to oncoming danger. It seems that science is already advancing on some of Spider-Man's super traits, and it may only be a matter of time before everyone can shoot and swing just like him.

Victor Mateevitsi at the University of Illinois, has developed a suit covered in sensors, meaning wearers can 'feel' objects around them even when they cannot see them. As a science geek himself, Spider-Man also invented web-shooters, which are mounted on his wrists and shoot a strong, sticky, web-like substance.

Spider silk is incredibly strong, with a tensile strength greater than a steel wire of the same thickness, meaning it has been suggested for many applications.

Researchers at Utah State University have genetically modified silkworms to produce spider silk in large quantities, ready-spun into useable threads, and a Japanese company Spiber has developed over 250 different types of artificial spider silks, with uses including bulletproof vests and artificial blood vessels.

Another of Spider-Man's powers is the ability to climb up walls and stick to ceilings, just like a spider. The gecko is a creature in nature that can also do this thanks to toe-pads covered in millions of tiny hair-like protrusions known as setae. There are around 14,000 of these per square millimetre, resulting in a very high surface area. It is this large surface area that allows van der Waal's forces to attract the gecko's foot to the wall. Van der Waal's forces are weak interactions caused by positive and negative charges on the adjacent molecules attracting one another. Although these charges are very small and only temporary, the large cumulative surface area of the hair-like protrusions on the gecko's toe allows for so many Van der Waal interactions

Image: Ricky Brigante, insidethemagic

to occur that the overall effect is strongly attractive. In fact, the toe-pads of a typical 70 g gecko could actually support a weight of up to 133 kg.

The strength of this adhesion, coupled with the fact it can work on a wide variety of surfaces, means it could be exploited for adhesives and could also be used in space, where conventional adhesives collect dust or lose stickiness over time. In fact, such biological technology has been the inspiration for The European Space Agency, which is developing Abigaille, a wall-crawling robot designed to scuttle around the outside of satellites and space stations to mend machinery. Abigaille's six legs use gecko technology to cling to the spacecraft.

A more worthwhile application of this technology would be gloves and shoes allowing us to climb walls just like Spider-Man, although how well you'd be able to climb would still depend on how strong you are. Also, the heavier you are, the larger the surface area you'd need to have in contact with the wall.

Could invisibility soon be a reality too? Susan Storm, also known as the Invisible Woman, is a member of the Fantastic Four, who received their superpowers after being bombarded with mysterious 'cosmic rays' during an ill-fated trip to space, so they fall into the second superhero category. Susan can create invisible force fields and turn herself and others invisible by bending light waves.

In 2006, John Pendry proposed that a material could be made invisible in this way and later that year, researchers in the US produced a 'meta-material' that steered microwaves around it, meaning it appeared

**"PEOPLE WITH A MUTATION SIMILAR TO MÄNTYRANTA'S CAN CARRY UP TO 50% MORE OXYGEN IN THEIR BLOOD"**

invisible at microwave wavelengths. In 2007, this was extended to visible light. Unfortunately, these meta-material cloaks only work for very small objects, so I'll have to look elsewhere for my Harry Potter-esque invisibility cloak for now.

However, some superheroes didn't have to rely on cosmic beams or radioactive bites to gain their powers. Instead, they developed them themselves. Unlike Spider-Man and the Invisible Woman, Iron Man doesn't have any inherent superpowers. Instead Tony Stark, a multibillionaire technology genius, graduated from MIT aged just 17 and used his expertise and wealth to build himself a robotic suit of armour.

The Iron Man suit is equipped with repulsor beams in the palms and feet, which he uses both as weapons and to enable him to fly. Such a suit of armour would be incredibly useful in combat situations, so it should come as no surprise to hear that the US Army has been developing an exoskeleton called TALOS (Tactical Assault Light-Operator Suit).

The first three prototype suits will be in use later this year, and will hopefully be completed and available by 2018. TALOS will enhance the user's strength and endurance, as well as monitoring their health and performance and offering a layer of armour. Currently, it doesn't look to include any weaponry, and Iron Man-style repulsor beams seem to be some way off.

As an alternative, directed-energy weaponry could be the answer. These work by shooting lasers, microwaves or particle beams at a target. Depending on the type of energy used, these beams are capable of passing through walls and being invisible. The Active Denial System (ADS) is based on microwaves and works similarly to the microwave in your kitchen, by heating up water. Unlike your counter-top microwave, however, it is designed to be used on human targets, firing a 3.2 GHz beam to excite water and fat molecules, heating up skin to unbearable levels.

The idea is that the pain becomes too much to handle before it causes permanent damage, although in 0.01% of cases it has led to second-degree burns. ADS was previously deployed in Afghanistan in 2010 but was never used. This system probably couldn't be used in an Iron Man suit as it requires a lot of power, making it very bulky. The original ADS had to be carried in a dedicated Humvee, meaning it probably won't be at hand-held size for some time.

So technology is certainly well on its way to making me into a superhero, but are there people out there who have got lucky in the genetic lottery or picked up superpowers during their lifetime?

Many superheroes, such as the super-fast Flash, show superhuman endurance. Eero Mäntyranta won three Olympic gold medals for Finland in cross-country skiing. This is one of the most physically demanding endurance sports and uses every muscle group, requires massive oxygen consumption and burns more calories than other sports.

Mäntyranta had a mutation in the EPOR gene, which produces a protein that responds to erythropoietin (EPO) and causes more red blood cells to be produced, increasing the oxygen-carrying capacity of the blood. Because of this, EPO is banned by the World Anti-Doping Agency, but has been widely used in sports, particularly cycling. People with a mutation similar to Mäntyranta's can carry up to 50% more oxygen in their blood, giving them a massive advantage over competitors without needing to dope.

Susan Storm's husband and teammate Reed Richards, also known as Mr Fantastic, has a rubber-like body, capable of being stretched and formed into all kinds of shapes. Similar to this, Garry 'Stretch' Turner suffers from Ehlers-Danlos syndrome, caused by a mutation to the collagen synthesis pathway.

Collagen is responsible for the structure of connective tissue and skin, so defective collagen production can lead to weaker connective tissue. In Turner's case, this has led to him being crowned Guinness World Record holder for the world's stretchiest skin. People with Ehlers-Danlos syndrome can also have very flexible joints thanks to the weaker connective tissue, but it can lead to complications such as arthritis and joint pain, neither of which Mr Fantastic seems to have problems with.

As a child, Matt Murdock was blinded by radioactive waste. Having taken away

Image: Riccardo Bandiera

one of his senses, the accident heightened his others, meaning he is able to use his excellent sense of hearing like sonar, exploiting echolocation in the same way that bats and dolphins can.

> THE TOE-PADS OF A TYPICAL 70G GECKO COULD ACTUALLY SUPPORT A WEIGHT OF UP TO 133 KG

Numerous blind people outside the pages of comic books are similarly able to get around using echolocation. Intriguingly, brain scans have shown that these people use the part of their brain normally reserved for visual processing to interpret the echoes they hear, with no response in the auditory processing regions, suggesting their brains have been retrained to interpret the echoes as visual input rather than sound.

Image: Sam Howzit

As an alternative to technology, could I gain superpowers in some other way? The Incredible Hulk came into being when Dr Bruce Banner was blasted with microwave radiation. As we've seen with the ASD weapon earlier, microwave radiation is unlikely to cause mutations, instead heating up the body and possibly causing burns.

After being cured of his original Hulk affliction, Banner chose to restore his powers by using a gamma ray machine. Gamma radiation is at the highest frequency end of the electromagnetic spectrum, meaning its photons have extremely high energy. When the photon hits a molecule, it can remove an electron, ionising the molecule and making it highly reactive. Gamma radiation is the most damaging form of ionising radiation, penetrating into the human body and damaging DNA. Depending on the dosage, gamma radiation can cause radiation sickness, cancer, or simply immediate incineration. It's unlikely to turn you into the Hulk.

As far as I can tell, I haven't got any superpowers, so the genetic route isn't going to help me in my superhero quest. Exposure to radiation is also much more likely to leave me dead or deformed than turn me into the next Hulk, so I'm left with technology as my only route to comic book immortality. Thankfully, it looks like science is catching up with fiction. Powered exoskeletons are starting to be used by the US military, gecko-based technology could help me climb walls, and arrays of sensors can alert users to incoming threats. The invisibility cloak seems a little further off, but I'm well on my way to becoming an Avengers. Does anyone have Nick Fury's phone number? ■

# AT OUR LIMITS: EXTREME PHYSIOLOGY

*How far can the human body be pushed?* ***Ellie Pinney*** *investigates the super endurance capacities of our physiology.*

The human body is surprisingly adaptable, but everything has its boundaries. Just how deep is too deep? How cold can we go? And at what heights do we truly reach our upper limits?

## *Under pressure*

The invention of the steam train in the 19th century sparked widespread construction of bridges and tunnels. Hundreds of workers spent their days laying foundations inside huge chambers filled with compressed air to keep the water out. On returning to normal pressure after work, the men would often experience a bizarre range of symptoms, from itchy skin to severe joint pain, paralysis and even death.

We now know this condition as decompression sickness or 'the bends', most often experienced today by divers who return to the surface too quickly. This sickness is caused by the formation of air bubbles in the blood. Breathing whilst under great pressure causes more gas to dissolve in the body's fluids than normal. In solution, this extra gas is harmless, and during a slow ascent the lungs expel it safely.

However, rapid decompression causes the extra gas to come out of solution as bubbles, some of which can be large enough to fatally block small blood vessels in the lungs and brain, and may also trigger blood clotting. Most commonly though, bubbles collect in the joints, causing excruciating pain and preventing the victim from extending their arms and legs – hence the name 'the bends'.

But the threat of pressure doesn't end there. Divers must also avoid what has been christened 'the rapture of the deep': nitrogen gas (78% of the air we breathe) becomes toxic at high pressure, with effects similar to alcohol, namely euphoria and over-confidence. Intoxicated divers have been known to offer their mouth-pieces to passing fish!

Image: Flickr / saspotato

As a result, compressed air can't be used at depths below 30 metres. Instead, divers breathe an oxygen-helium mixture called 'heliox'. Unfortunately, when heliox is used at depths below 200 250m, divers risk the onset of High Pressure Nervous Syndrome, which causes tremors, nausea and dizziness. Fortunately, this condition can be held off by adding a small amount of nitrogen back into to the gas tank. Breathing this 'trimix', humans can theoretically endure super depths of up to 450m.

> INTOXICATED DIVERS HAVE BEEN KNOWN TO OFFER THEIR MOUTH-PIECES TO PASSING FISH

## Chilling out

When our body temperature falls, several coping mechanisms act to delay serious injury. Firstly, we begin to shiver. These muscle contractions require energy production by respiration, which also generates heat. Blood vessels in the skin constrict to reduce surface heat-loss, dilating only occasionally to prevent tissue death by providing oxygen.

If the temperature falls further, the constriction becomes constant and the extremities are sacrificed to preserve core body heat. This causes frostbite to set in as ice crystals form inside cells, puncturing their membranes and killing them one by one.

Hypothermia begins when the body's core temperature falls below 35°C (from 37°C). As hypothermia progresses, patients become tired and uncooperative. Their speech slurs and they can't make rational decisions. The body begins to shut down at around 32°C due to lack of energy, and below 30°C the victim loses consciousness. Soon after, they suffer cardiac arrest.

However, hypothermia can be beneficial too, when extreme cold causes the body to enter a state of 'suspended animation', our metabolic (chemical) processes slow to a point where cells can survive on just a fraction of the oxygen needed at 37°C. This can preserve the brain cells of hypothermia victims during long periods without blood flow.

In 1999, a Norwegian skier fell unconscious after tumbling headfirst through ice into fast-flowing water. She arrived at hospital two hours after her heart had stopped with a record-breaking core temperature of just 13.7°C, yet her heartbeat returned on re-warming. Incredibly, she recovered without brain damage.

As they say in emergency medicine, 'nobody is dead until they're warm and dead'. Hospitals now use hypothermia therapeutically: surgeons often cool their patients to as low as 10°C, allowing them to cut off the brain's blood supply for up to 15 minutes without causing brain damage.

## Cool facts

In 2013, specialist London Ambulance teams began administering roadside therapeutic hypothermia to cardiac arrest victims, using a cooling nasal spray.

Babies have a built-in heating system: pads of 'brown fat', packed with special heat-generating mitochondria, cover their shoulder blades and neck. This disappears before adulthood.

## Living the high life

As altitude increases, atmospheric pressure decreases, and we take in less oxygen with each breath. This starts to become problematic at just 2,400m above sea level, where a lack of oxygen in the body can lead to something called 'Mountain sickness', causing headaches, nausea and dizziness. At 4000m around 40% of people will be affected, but we don't yet know why some suffer more than others.

Descent fixes Mountain sickness almost immediately, but ascending further makes matters much worse. Blood vessels in the

> EVENTUALLY THE BREATHING RATE AT HIGH ALTITUDE CAN REACH FIVE TO SEVEN TIMES THAT AT SEA LEVEL

lungs start to react to the lack of oxygen in the air by constricting. This natural response is helpful at sea level, allowing areas of the lungs with the most airflow to have the best blood supply, but at high altitude, the entire lung experiences low oxygen: blood vessel constriction happens everywhere, not just in patches.

As a result, blood pressure in the lungs shoots up, forcing fluid out of the vessels and into the alveoli (air sacs). This is called pulmonary oedema. Left untreated, the victim effectively drowns in their own fluid.

It's not all bad news though. The nasty effects of altitude can often be avoided – or at least delayed until higher up – by ascending slowly. Given time, the body can acclimatise to altitude by increasing the breathing rate to bring in more oxygen. This process is gradual, involving chemical changes driven by the kidneys, but eventually the breathing rate at high altitude can reach five to seven times that at sea level.

Acclimatisation also increases the number of circulating red blood cells, boosting the blood's oxygen-carrying capacity. It's this adaptation that athletes cash in on by training at altitude, since levels remain high for some time back at sea level, and can improve sporting performance. Acclimatization has its limits though. Above 8000m – known to climbers as the "death zone" – no human body can adapt sufficiently. An extended stay up here without supplementary oxygen would not end well.

## *Record highs*

In 1978, Italian and Australian mountaineers, Reinhold Messner and Peter Habeler became the first climbers to reach the summit of Everest (8848 m) without supplementary oxygen, making a speedy dash into and out of the death zone.

The 1968 Mexico City Olympics took place 2,240m above sea level. Sprint events – where breathing is unimportant – saw World Records smashed due to reduced air resistance at high altitude, but endurance athletes underperformed consistently due to the low oxygen levels. ■

Image: Wikicommons / Winky from Oxford

# MEGA MATERIALS

*Year-on-year nanotechnology takes huge strides.* ***Daisy McInnerney*** *puts under the microscope the science of atom-level material manipulation.*

Hold the 4th century Lycurgus cup up to the light and watch as it mysteriously morphs from green to red. This mystical colour transition is not magic though, it's nanoscience: tiny colloidal particles of gold and silver cause the glass to flit between red and green depending on the direction of the light source. Humans have inadvertently capitalised on the properties of tiny, nanoscale properties like this for centuries, from manufacturing stained glass windows to forging Damascus sabre blades.

The potential of harnessing this sub-molecular domain was first presented to the world by effervescent physicist Richard Feynman in his famous 1959 address There's Plenty of Room at the Bottom. However, it wasn't until the invention of the scanning tunnelling microscope in 1981 that scientists were first able to 'see' materials on such a minute scale. And in visualising this microscopic world, a window was opened to a whole new realm of material science.

So just how small are nanostructures? A nanometer is one billionth of a metre, which is about a hundred thousandth of the diameter of the average human hair. Nanotechnology encompasses the study and application of matter with dimensions between 1 and 100 nanometers. This

> A PLETHORA OF POSSIBILITIES ARISE FROM FIDDLING AROUND WITH ATOMIC ARRANGEMENT

means that scientists are not manipulating the molecules in a material, but the arrangement of the atoms themselves.

In 1991, a team of Japanese scientists constructed a new formation of carbon atoms – the carbon nanotube. It consisted of a single layer of carbon, just 1-atom thick, rolled into a cylinder. Carbon nanotubes can be hundreds of times stronger than steel, yet they are six times lighter. Alternatively, they can be arranged into highly efficient semi-conductors that outperform copper at carrying electrical current.

Image: Flickr / Willtron

The nanotube is just one example, but a plethora of possibilities arise from fiddling around with atomic arrangement. Many of the early applications already quietly influence our lives: the scratch-resistant coating on spectacles is derived from engineered aluminium silicate nanoparticles; almost all high-powered electronic devices rely on the superior transistor structures built from nanomaterials; even dentistry is benefiting from nanoceramic implants that have been 'tuned' to attract bone cells from surrounding tissue.

The field of nanotechnology research is booming. This year, the journal Nature Nanotechnology published research demonstrating new luminescent nanocrystals that can penetrate deep into biological tissue, revolutionising bio-imaging. In the same month, scientists built gold nanoshells that can encapsulate chemotherapeutic drugs, and target them specifically at cancer cells whilst leaving healthy cells unharmed. Ongoing nano-work points towards the development of energy efficient fuel cells, food packaging with improved shelf life, bacteria resistant textiles, and super-strong and super-light construction materials that could revolutionise transport infrastructures.

As with most growing fields in science, the results of nanoresearch are likely to quietly trickle into our lives. Rest assured though, these tiny structures hold a transformative power far greater than their diminutive size suggests and that will undoubtedly influence scientific development on a grand scale. ■

# SUPER SPEEDY EVOLUTION

*There are no rules about the rate of evolution.* ***Lauren Hoskin*** *unveils the fastest, and some of the slowest, evolving species.*

From the tiniest microbe to the largest whale, all species on earth are constantly evolving, albeit some more quickly than others. Just a single mutation can start a ripple effect, establishing the transformation of one species into another. But why and how do some organisms evolve faster than others?

The slowest evolving animal alive is the elusive elephant shark. This fish inhabits the waters around southern Australia and New Zealand at depths of up to 200 meters. Using its snout, it hunts for shellfish living in the sand. The elephant shark is one of few animals in a group called the Chimaeras, whose skeletons are made from cartilage rather than bone. Chimaeras are closely related to sharks, rays and skates but the elephant shark split off from these other fish some 420 million years ago and has changed little since then.

Image: Jacob Hoefnagel

Surpassing all norms, the elephant shark managed to escape evolutionary pressures through great periods of change. For example, through analysing its genome, a team of scientists were recently able to confirm that this species is missing the gene family responsible for the development of bone. It appears that this gene eventually occurred through a duplication event, which then gave rise to the evolution of all bony vertebrates.

Evolution is a complex maze, so there is no one reason why one particular species shouldn't evolve while another stays the same. It is likely that the elephant shark has been in fairly stable environmental conditions over the past 420 million years, or else it might have needed to adapt to changes that could have included climate, new predator-prey structures or food scarcity.

Several situations create the rapid evolution of species. When a group of animals become stranded in a small area such as an island, a cave or an isolated mountain, a remarkable event occurs: the larger bodied animals tend to shrink and the smaller bodied animals tend to enlarge. This situation has been called 'The Island Rule'. When stranded, the larger animals have an evolutionary incentive to eat less and reach sexual maturity earlier in order to reproduce more frequently. Both of these pressures rely on an animal becoming smaller. Although now extinct, there are many examples of dwarf elephants colonising Mediterranean islands throughout the ages. Island dwarfism in elephants has been known to take place in less than 100,000 generations, a relatively short evolutionary time for these large mammals.

Meanwhile, smaller animals are free from many of the predatory pressures they might have previously succumbed to on the mainland. For this reason they are naturally selected for size since they no longer need to hide from predators, and being larger means being able to fight the competition for food. A famous example of island gigantism is the dodo, a gigantic flightless pigeon which was prevalent on the island of Mauritius until around 1680.

The guppy, a small freshwater fish, currently holds the gold medal among verte-

> THE GUPPY, A SMALL FRESHWATER FISH, CURRENTLY HOLDS THE GOLD MEDAL AMONG VERTEBRATES FOR ITS EXTREMELY SHORT EVOLUTIONARY TIMESCALE

brates for its extremely short evolutionary timescale. In an experiment to measure how fast it could evolve, a team of scientists split a group of guppies into two and placed them into distinct parts of a river. One half inhabited the top of a waterfall where all predators were excluded whilst the other half inhabited the lower area of the stream which was abundant with predators.

The guppies at the top experienced little predatory pressure and within just ten years had evolved to become much larger and produce fewer offspring. In a similar case to the dodos, the guppies were selected to become much larger since this helped them to compete for the limited food supply.

Despite ten years being exceptionally fast for a vertebrate to evolve, microbes far exceed this timespan with an ability to do so over a matter of days. Bacteria have a number of characteristics that help them to evolve this fast, including being able to reproduce quickly through short generation times. Under optimal conditions, some bacteria can multiply their number by a million within twenty generations.

A typical bacterial strain such as Staphylococcus aureus, which is the non-antibiotic-resistant version of MRSA has a generation time of about half an hour. This means that within just ten hours, one microbe could reproduce to create an army of a million.

The second reason for their fast-paced evolution is their large population sizes and close living quarters. In these large communities, there is a much greater chance of mutations arising as well as a greater ability to spread them quickly. Bacteria, like all other animals, are able to pass genes down


William |Warby

vertically from parent to offspring. Yet they also possess another interesting trait which helps them to transfer mutations exceptionally fast; the ability to transfer genes horizontally.

Horizontal gene transfer is the process of passing DNA between each other through injection. Bacteria are able to put their DNA into small self-replicating circles called plasmids and so pass it to others, even of different species. Once received, bacteria can incorporate the new DNA into their own genome.

This is particularly handy for the bacteria, and particularly dangerous for humans, since these microbes do not even have to reproduce in order to pass their beneficial genes on; they can simply transfer some of their DNA to another species that lacks it. In the case of antibiotic resistance, it therefore takes just one microbe to have the resistance gene and it can spread like wildfire, especially when the population encounters the antibiotic and so the rest of the population die out, leaving space and nutrients for the resistant population to expand into.

Studying evolutionary speeds can help scientists in a number of ways. Investigating the traits of both extremely old species and of constantly evolving species tells us about our genes and which ones give us certain characteristics, which can help us develop new treatments for diseases. Additionally, we can exploit microbes that evolve quickly to create potential new medicines by using them as little protein factories.

Bacteria will probably be here for as long as life survives on Earth and the elephant shark may well remain unchanged for another 420 million years, but our big question is; how will we evolve during that time?

# DATA BLOCK: THE COLOSSAL HIDDEN INTERNET

*Most of the Internet could never be returned in a Google search.* ***Rosamund Pearce*** *casts light on the Deep Web.*

Underneath the surface hubbub of tweets, trolls and the profound musings of Justin Bieber, there lies a dark and mysterious world called the Deep Web. Invisible to most search engines, it is home to a diverse range of characters, from journalists to cybercriminals.

As we come to realise just how flimsy Internet privacy is, many are embracing the anonymity offered by Deep Web browsers. What was previously thought of as an accumulation of the Internet's past may in fact represent a look to the future. Now, with new data mining techniques, science is being used to explore this vast internet underworld.

The Internet can be compared to an iceberg. While the cliffs above the water may seem pretty big, far greater is the invisible mass below the surface. Only 0.03% of the web can be seen by search engines. The remaining 99.7% is a vast repository of derelict or hidden content that general-purpose web crawlers cannot reach. It isn't a particular destination - it exists in various interstices of the virtual world.

Some parts of the Deep Web cannot be accessed by traditional web browsers at all. These secretive file-sharing networks are known as 'dark nets', and require specially downloaded software such as The Onion Router (Tor). Tor encrypts and anonymises traffic masking the identity of its users.

It is this anonymity that not only allows the proliferation of pockets of counterculture and enables freedom of information in countries with censorious regimes, but that also attracts the murkier characters of the Deep Web. With the crypto currency Bitcoin, users can buy almost anything from rhino horns to olive oil. And despite much fabrication and hysteria surrounding darknets, there is certainly some genuinely disturbing content, such as child pornography and adverts for contract killers.

The anonymising nature of data cuts both ways – it is impossible to tell the casual user from law enforcement. It was this that led to the downfall of the infamous blackmarket Silk Road, which was shut down by the FBI in October last year. Some darker activities are also curbed by members of the com-

> DESPITE OFTEN BEING THOUGHT OF AS A PARAGON FOR OPENNESS AND TRANSPARENCY, THE INTERNET HAS IN FACT BEEN DRIVEN BY A DESIRE FOR SECRECY FROM ITS GENESIS


munity itself, such as the hacking collective Anonymous.

But despite its mysterious name much of the data in the Deep Web is unremarkable research data or defunct pages such as old flight bookings. All manner of everyday web companies, like Amazon, Twitter or eBay, have Deep Web content. But although mundane, such information is also potentially valuable.

Information is arguably the most coveted commodity of our new Information Age, and so the value of Deep Web data is immeasurable. New approaches are being pioneered to open up these vast data mines. Like deep-sea adventurers, studies

**“ONLY 0.03% OF THE WEB CAN BE SEEN BY SEARCH ENGINES”**

like BrightPlanet are exploring the nature of information on the web. Science, or natural philosophy as it was, originally focused on the study of the natural world. Now, thanks to the incredible pace of advancement we are exploring a second-level reality that we have ourselves created.

Traditional search engines create their search results by crawling surface web pages, following one hypertext link to another. Like ripples travelling across a pond, crawlers are able to obtain pages further and further from their starting point. To be discovered, a web page must be static and linked to other pages. Although Deep Web content is stored in searchable databases they only produce results in response to a direct search. They cannot ‘see’ Deep Web content because those pages do not exist until they are created as the result of a specific search.

Scientists at the University of Utah have been developing ‘DeepPeep’ - a specialist search engine that trawls these dynamic databases. The challenge is to obtain the information automatically - it is obviously impractical to ask each website individually for their contents. To do this DeepPeep uses a technique called ‘iterative probing’- first, it analyses the database’s form for clues. For instance, the words “assignee” or “invention” are likely to indicate a patent database. DeepPeep uses these clues to fill in the forms, extracts new keywords from the results, and then repeats the process.

Search providers such as Google and Kosmix are also getting involved, using new, ‘directed query’ search engines. Others are concentrating on more specific areas. Since most personal information can’t be found on the surface web, the query engine ‘Pipl’ has been designed to retrieve information about people from the Deep Web.

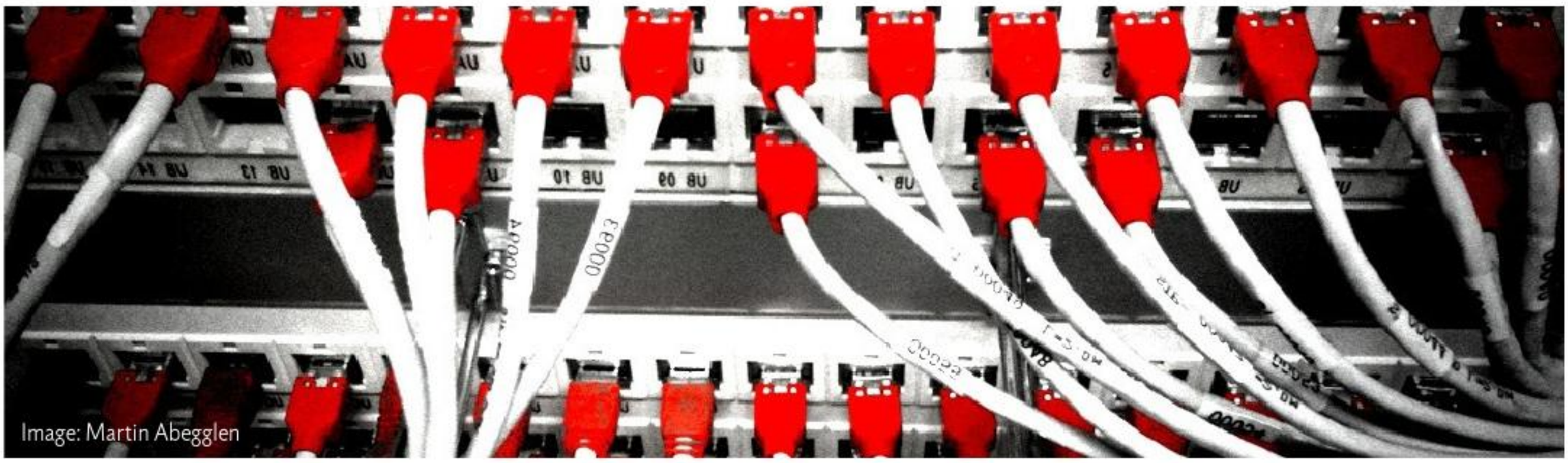


Image: Martin Abegglen

Indexing the whole web is not yet feasible, mostly because of the sheer scale of the data. The surface web alone grows at a rate of around 7.5 million documents per day with growth now exceeding the crawling ability of search engines. It is also difficult because some sites block crawlers, to protect commercial or criminal interests.

Despite often being thought of as a paragon for openness and transparency, the Internet has in fact been driven by a desire for secrecy from its genesis. The 'ARPANET', a 1969 precursor of the Internet, was part of a US defence project. In fact Tor is based on military encryption technology co-opted by cypherpunks.

Nowadays we are so used to its omnipresence that it is easy to forget just how much Internet technology has advanced. Remember when finding a website was like sending a letter? You needed to know the address, and in many ways browsing the Deep Web is comparable to browsing the Internet before the invention of search engines. Finding sites is a serendipitous activity, and pages have a 'dial-up design' aesthetic.

There is no doubt that the Internet is a wonder of the modern world – indeed is it in fact largely responsible for the modern world. Its stratospheric expansion into our lives has revolutionized culture and commerce. It has opened up the global marketplace to everyone's backroom and helped to orchestrate the Arab Spring revolutions. But people are also increasingly worried about the power of this super-science.

Recently featured in *House of Cards*, the Deep Web seems to be having something of a cultural moment. As we put more and more of our lives online, the flimsy nature of digital privacy becomes an ever-greater concern. Indeed, The *Guardian*'s National Security Agency revelations of 2013 showed just how all-encompassing state surveillance can be. More and more people are embracing the anonymity offered by parts of the Deep Web. It may sound inaccessible but the reality is that it's a few clicks away – all that's needed is a download and a degree of technical know-how.

In 1962 computer scientist J.C.R. Licklider envisioned a 'Man-Computer symbiosis' where everyone on the globe would be connected in an 'Intergalactic Network'. Fifty years later we are more connected than Licklider would ever have dreamed, even our household appliances are now being given Internet capability. But can science ever catch up with this vast data mine that it has created? How far will this super-science infiltrate our lives? Will more of us resort to encrypted browsers? The place of the Deep Web in the future of the Internet remains to be seen. ■

### INFORMATION SUPERHIGHWAY

- About 250 billion emails are sent every day, although 80% of them are spam.
- There are over 5,700 tweets tweeted per second, and over half a billion per day.
- More than a billion people watch YouTube videos each month for an average time of four hours.
- Six out of seven people on Earth have access to the internet and around 2.4 billion people will go online today.

# REVIEWS

## 50 VISIONS OF MATHEMATICS

*Book review*

*Sam Parc (foreword by Dara Ó Briain)*
*Oxford University Press (2014)*

In mathematics anything is possible, even the assertion 2+2=5. So goes the story in George Orwell's darkly dystopian novel, *1984*, when the hero of the novel realises that even the most fundamental truths that he accepted in his life could be changed at the behest of Big Brother. That the simplest 'truths' of mathematics could be violated in such a way by a government in possession of total power over the lives of its citizens is emblematic of the cultural role that mathematics, the Queen of the Sciences, plays in the definition of truth in our everyday lives.

*50 Visions of Mathematics* has been published to celebrate 50 years of the Institute of Mathematics and its Applications. It contains 50 original pieces of writing from top mathematicians and science communicators, including the mystery of the number 6148. Through its wide-range of articles written on subjects varying from string theory to quadratic equations, as well as its 50 colour photos, it captures the very heart of what mathematics is really about: elegance and beauty.

The articles are generally written in a light-hearted and accessible way. One highlight for me is Marcus du Sautoy's essay on mathematics as 'the language of science', something he asserts Galileo strongly affirmed as he developed a scientific method for the Enlightenment. Other fascinating essays are on subjects including 'proof by pizza', barcodes, the maths of footballs and a mathematical challenge set for the Phoenician princess Dido.

Finally, if you want to find out what makes the number 6148 so mysterious, then I recommend you read Yutaka Nishiyama's article. You may never look at mathematics in the same way again. ■

DARIUS NIKBIN

## RISK SAVVY

*Event review*

*Royal Institution*
*20 May 2014*

Remember the volcanic ash cloud over Iceland? The subprime disaster? Or mad cow disease? Every crisis makes us worry; until we forget it and start worrying about the next one. When something goes wrong, we are told that the way to prevent a new crisis is through better technology, bigger bureaucracy, and stricter laws.

Gerg Gigerenzer, Director of the Center for Adaptive Behaviour and Cognition at the Max Planck Institute for Human Development, believes there is an alternative solution: risk savvy citizens. During his talk at the Royal Institution, explained how, in a technological society, everyone can—and should—learn to deal with risk and uncertainty for themselves.

One way is to keep in mind that risk and uncertainty are not the same thing. When all the alternatives, probabilities, and consequences are known, we are dealing with risk. Risk requires logic and statistics. By contrast, in the world of uncertainty not every factor can, or will, be known. So decisions on questions such as who you should marry, who you can trust and where you should invest money require intuition and rules of thumb known as heuristics, not necessarily hard logic and stats.

The problem in our society is that statistics are placed above intuition and heuristics. Andrew Haldane, the Bank of England's executive director for financial stability, explained in his 'The dog and the frisbee' speech, that in complex decision-making problems, simple rules sometimes do just as well as complex solutions, if not better.

Our modern democracies need risk-savvy citizens who will not be manipulated into unrealistic hopes and fears or easily threatened into surrendering their money, their welfare or their liberty.

Read the full article online at www.isciencemag.co.uk. ■

NICOLE SKINNER

## SCIENCE OF DISCWORLD IV: JUDGEMENT DAY

*Book review*

*Terry Pratchett, Ian Stewart, Jack Cohen*
*Ebury Press (2014)*

Terry Pratchett once again teams up with mathematician Ian Stewart and biologist Jack Cohen for *The Science of Discworld IV: Judgement Day*. This time the intrepid trio try to answer the 'REALLY big questions' about God, the universe and everything in between.

The *Science of Discworld IV* follows the format of its predecessors by interspersing some truly excellent science writing with a bit of light entertainment from the fictitious *Discworld*. In *Discworld* an argument has erupted between magic and religion: an argument over the ownership of roundworld, a 20cm globe that normally sits on a dusty shelf in Unseen University. Did I mention that this globe is actually the planet Earth?

As a popular science book *The Science of Discworld IV: Judgement Day* is unparalleled. Pratchett, Stewart and Cohen deftly explain complex scientific concepts with a wonderful set of tongue-in-cheek analogies. For example the hunt for the Higgs Boson is a bit like trying to find out what a piano is made of by hurling pebbles at it and studying any musical notes that result.

If you are looking for a humorous popular science book full of fascinating snippets from the worlds of cosmology, philosophy, physics, biology and mathematics, then this book is for you. If you are not a particular Pratchett fan you may want to skip the *Discworld* chapters and stick to the science bits, but I feel you would be missing out. I for one enjoyed the fictional narrative and felt it very much added to the philosophical discussions at the heart of this intriguing and highly entertaining book. ■

ELLEN MEEK